Chapter

Evaluation of a Landscape Irrigation Management Strategy to Support Abu Dhabi Update Its Water-Related Standards

Geraldine Seguela, John Richard Littlewood and George Karani

Abstract

This chapter discusses an landscape irrigation (LI) strategy to enable 100% non-potable water reuse through soil improvement, thereby reducing the environmental impacts. The case study site is a medical facility including 33,257 m^2 of landscaping in Abu Dhabi (AD), the capital of the United Arab Emirates. The aim of this research is to increase net-carbon sinks, a pillar of decarbonization, as the basis for a proposed protocol to implement soil improvement techniques for the landscape architecture/agriculture industries. The interventions, based on AD soil and water recycling standards, included three different soil additives in 2016 and 2017, together with the calculation and implementation of a suitable irrigation rate to establish LI demand and reduce a five-month shortfall in air-conditioning condensate water supply. The intervention results show the case study irrigation rate was 50% less after soil improvement than the AD Municipality irrigation standard and that the LI condensate water deficit decreased by 8046 m^3, a 42% reduction. The research demonstrates that carbon sinks can be increased through improved soil management; this highlights the need to update AD's water-related standards to help the city achieve its 2030 target of a 22% reduction in greenhouse gas emissions.

Keywords: water policy, climate change, water quality criteria, recreational water, bacteria, sodicity, salinity, soil acidity, irrigation and drainage, heavy metals and metalloids, soil interpretations

1. Introduction

1.1 Research background

The work documented in this chapter forms part of the first author's Professional Doctorate in Engineering research, a change project implemented at a medical facility case study (MFCS) in use since 2015. The MFCS is a 364-bedroom hospital located in Abu Dhabi (AD), the capital of the United Arab Emirates (UAE), a hot, desert-type climate as classified by Köppen and Geiger [1]. The 33,257 square meters

(m^2) landscape at the MFCS represents 50 percent (%) of the MCFS footprint and uses air-treated condensate water (CW), a product of air conditioning, for outdoor irrigation purposes to avoid the usage of energy-intensive desalinated water [2]. Due to peak CW formation occurring in summer, there is a shortfall in winter (established at −19,235 cubic meters per year (m^3/year) in 2016). Water and soil data were used to develop sustainable water consumption and reuse (SWC) strategy forming the basis of a water conservation protocol [3] whereby soil improvement for the landscape is investigated as part of a mixed methods approach [4–6]. This strategy would enable the MFCS to address the five-month CW shortfall, reduce the outdoor use of desalinated water, and, consequently, would reduce the MFCS's building systems water and energy consumption, operation and maintenance cost and practices, and ultimately greenhouse gas (GHG) emissions. The outcome of the research project demonstrated that carbon sinks can be increased through improved soil management [7], helping AD achieve its 2030 GHG emissions target [8].

1.2 The context of water: Soil Nexus in Abu Dhabi

Of the world's 19 most water-scarce countries, 13 are Arab countries [9, 10]. Per capita water availability is below 200 m^3 per year in eight Middle Eastern countries (**Figure 1**), including the UAE [12]. In December 2020, the UAE ranked 10th on the list of the 17 most water-stressed countries in the Middle East and North Africa (MENA) region [12].

AD's annual water consumption was estimated to be 2.49 billion m^3 in 2017 [13], and peak demand is predicted to more than double by 2030 [14]. In response, AD has embarked on a USD 5 billion programs based on an aquifer storage and recovery approach [15]. This program aims to build capacity so that local aquifers can be used as strategic reserves for desalinated water [16].

Analysis of water demand by sector and by type of water in AD shows that 100% of potable water is used for commercial, residential, and industry buildings, including

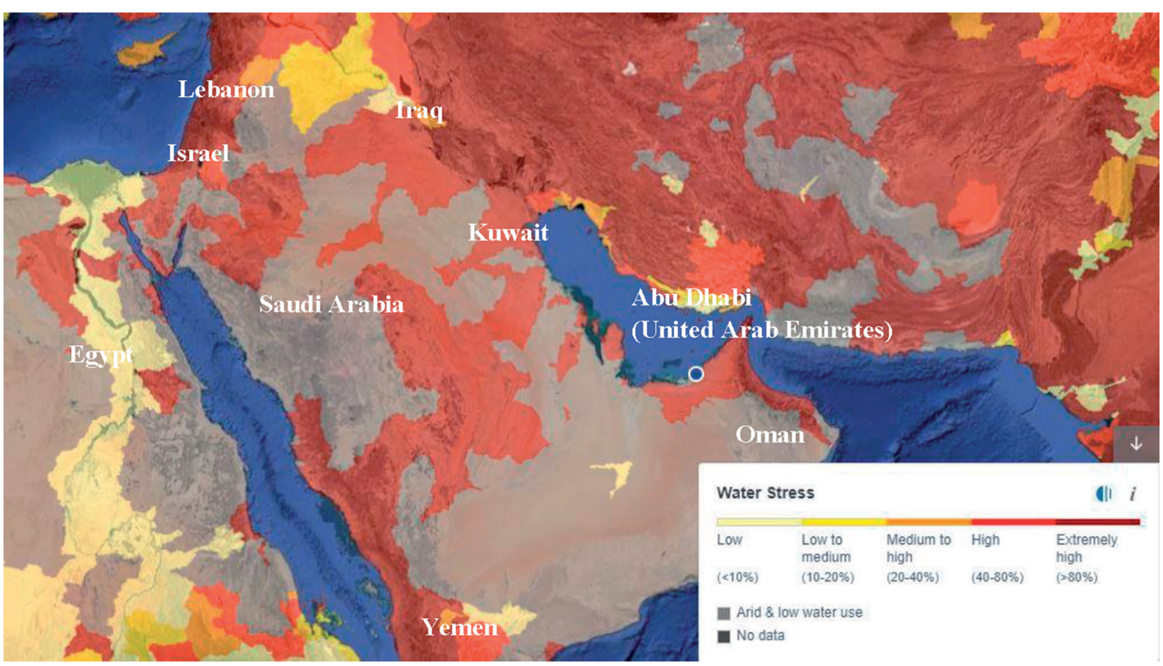

Figure 1.
Water Stress in the Middle East including the UAE by 2030 [11].

outdoor landscape irrigation (LI) [17]. Thus, a significant opportunity exists to conserve water for outdoor use.

Exacerbating the issue of water availability, the landscape of AD is dominated by sandy, salty soil with very low water-holding capacity and experiences high temperatures and relative humidity, limiting plant growth [18–20] and locally grown food [21]. In arid and semi-arid regions, soil qualities are frequently physically, hydraulically, and chemically deficient due to their sandy natural state and exposure to harsh climatic conditions [14, 19, 22].

Consumptive water use is the sum of two factors: transpiration and evaporation [23]. While agriculture is responsible for the bulk of water consumption—through both evaporation from land surfaces during irrigation and transpiration from plants [24]—conservation techniques for urban landscape are characterized by site modifications, diverse use, and complex microclimates [25]. In AD, the greatest potential for GHG emission reductions by 2030 is from combined electricity and water production (22% of business as usual (BAU) emissions), through tariff reform, building and efficiency standards, demand-side management, and district cooling and appliance efficiency standards [8].

1.3 Case study background

In 2016 and 2017, the MFCS Energy Monitoring and Control System (EMCS) recorded LI water deficits (predominantly occurring in the winter and spring months) of 19,235 and 11,189 m^3, respectively, representing a 42% year-on-year reduction. The use of CW and desalinated makeup water for LI decreased by 8% from 37%, from 91,564 to 83,960 m^3, over the same period. Additionally, total LI consumption of the combined air handling unit air conditioning (AHU A/C) CW and desalinated makeup water decreased by 18% from 2016 to 2017. These results derived from the implementation of a series of interventions through an action research methodology including soil enhancement, soil quality testing against the Regulation and Supervision Bureau standard [26] and the Ministry of Climate Change and Environment soil standards [27], as well as valve flow audit and water demand calculations based on Abu Dhabi Municipality [28], Urban Planning Council [29, 30], and the United States Environment Protection Agency standards (U.S. EPA) [31, 32]. A pilot empirical project (PES 2016) was undertaken to verify that the application of a soil conditioner could improve (i) plant growth, and (ii) water retention in the soil, thereby assisting in reducing water demand by up to 50% against the U.S. EPA standard [32], delivered by a 5% adjustment to the soil.

1.4 Gap analysis

In relation to the knowledge gaps in practice—identified and summarized in **Table 1** below, coupled with the pilot empirical study (PES 2016) findings—it was found that the AD soil and water standards conflict with or disregard each other or lack clear directions for water savings in landscape irrigation (LI). For instance, the way the Regulation and Supervision Bureau (RSB) [26] regulates LI is by including criteria for trace elements; however, no concentration values are defined for salinity or essential nutrients. This could be beneficial to irrigation water, plants, and soils [34, 35, 39]. It was also found that the Ministry of Climate Change and Environment (MOCCAE) [27] soil standard does not clearly indicate minimum and maximum soil micro- and macronutrient concentration limits for soil maintenance. In addition,

Existing AD codes, standards, and strategies	Local water-related conservation regulations gaps
Guide to Recycled Water and Biosolids Regulations 2010 [26]	Soil quality standard for water conservation: Beyond the potential for hydrogen (pH) and copper, RSB does not offer other parameter limits such as electrical conductivity, sodium, calcium, and magnesium concentrations, which influence water-holding capacity in soil [33].
Ministerial Resolution 476 of 2007 concerning by-law of fertilizers and agricultural soil conditioners, Chapter two [27]	Soil quality standard for water conservation: Ministry of Climate Change and Environment (MOCCAE), formerly known as Ministry of Environment and Water (MoEW), does not offer parameters limits such as electrical conductivity, sodium, calcium, and magnesium concentrations, which influence water holding capacity in soil [34, 35].
Design Public Realm Guideline [29]	This document promotes irrigation interval days without mandating soil amendment with soil additives.
Irrigation Systems and Operation Maintenance volume 2C Section 02850 [28]	This document addresses irrigation rates for design and construction projects, but not for building operation. And the irrigation recommended is not in line with vegetation watering recommendations [36, 37].
International Building Code 2013, Chapter 29 Plumbing Systems [38]	Building hydraulics, such as landscape irrigation valve flow audit, is not addressed.

Table 1.
Local standards and policies gap analysis of water conservation in Abu Dhabi.

the Urban Planning Council (UPC) [29] guideline conflicts with Abu Dhabi Municipality (ADM) standard [28] with regard to seasonal months and landscape irrigation rates. Last, the only common ground of Department of Municipal Affairs and Transport (DMAT) [38] and UPC Public Realm Design Manual [29] guidelines for water conservation in landscaping is the regulation of reusing treated sewage effluent (TSE) and *Legionella*. None of the above standards address a common and clear water demand management strategy for landscape irrigation, a pillar of decarbonization [7].

1.5 Contributions to new body of knowledge in practice

The key original and significant contributions to the knowledge gap in practice from this research chapter are threefold.

Firstly, improving the management of water and soil increases net-carbon sinks [40] and offsets GHG sources (e.g., fossil fuel), because some CO2 will be returned from the natural carbon sinks [7], such as ocean and soil acting as CO_2 absorbers. Secondly, the soil in AD is classified by the U.S. Department of Agriculture [18] as having a very low water-holding capacity. Water-holding capacity and infiltration rates are ultimately linked [34]. Infiltration is the most important factor in the soil phase of the hydrological cycle [41]. The infiltration rate is measured according to the soil's ability to absorb irrigation water [42]. Thirdly, the choice of essential plant nutrients to include in applied irrigation requires considerable professional skill and experience, as hydrology and pedology are complex sciences [23, 34, 35]. The problem related to water need and environmental conditions arises when an essential plant nutrient element is needed, and water is not needed [27]. Irrigation is a water consumptive process, which is also energy-intensive to deliver [25]. Hence, in identifying ways to help minimize water wastage and decrease GHG emissions for a MFCS in AD, this chapter addresses gaps in practice. Recommendations for revision of the AD water and soil standards are introduced in Section 1.4 above and described below.

2. Materials and methods

The MFCS (Water Resources case study) uses a quantitative data collection process [4–6] which links to one of the overall research objectives of the research project: to test a water conservation framework for water resources through two interventions and two calculations, as described below in **Table 2**, and to analyze the data collected.

2.1 Pilot empirical study (PES) 2016

As per **Table 2**, a pilot empirical study (PES 2016) was conducted from April to September 2016, which comprised four elements:

i. Soil quality testing before and after soil solution applications A, B, and C including a hydro-activator fertilizer combined with compost and synthetic fertilizer (solution A), an organic soil conditioner (solution B), and an organic compost combined with a synthetic fertilizer (solution C). These three different soil solutions were applied to 8855 m^2 (out of 24,402 m^2) of the MFCS landscape area between April 2016 and September 2016 to evaluate the suitability of soil improvements for reducing the use of potable water for outdoor use and its effect on plant growth. The purpose of the comparison was to allow measurement of the relative effect of the soil conditioner treatment (independent variable) against the areas that received either no treatment (no water reduction) or a different treatment (Solution A and C) with a different water reduction.

SOIL enhancement interventions	WATER demand calculations
Pilot Empirical Study: PES 2016	**Pilot Calculation One: PPC1—2016**
• Soil enhancement trial: April–September 2016 including the following:	• Irrigation rate calculations pilot
○ Soil quality testing (March 2016) ○ Outdoor Valve Flow Audit Trial (December 2016) ○ Weekly Photographs ○ Energy Management Control System (EMCS) LI water consumption records	**Calculation One: Calc 1–2017** • Irrigation rate calculation implementation
Soil Intervention: SEI 2017	
• Soil enhancement implementation (April–May 2017) including the following: ○ Soil Quality Testing (June 2017) ○ Outdoor Valve Flow Audit (August 2017) ○ Weekly Photographs ○ EMCS records LI water consumption records	

Table 2.
Case study methodology summary.

ii. Audit of eight water valves out of 127 (connected to the irrigation controller and the LI water meters) to verify their flow accuracy (in l/m^3).

iii. Weekly photographs of the areas tested before and after the test to provide evidence of plant growth.

iv. EMCS records to monitor water consumption.

The intent of the pilot project (PES 2016) was to create and measure a credible outcome based on a cause-effect relationship within the research field setting (MFCS PES 2016 landscape area) [33]. Findings from this intervention have been published in Seguela et al. [33].

2.2 Soil enhancement implementation (SEI) 2017

The SEI 2017 intervention was conducted to reduce the water demand strategy onsite, following the successful implementation of the PES 2016, Pilot Project Empirical Study, Solution B.

As a result of the PES 2016 analysis, soil solution B was applied to the remaining of the MFCS landscape area (33,257 m^2–8855 m^2 = 24,402 m^2) including date palms, plants, shrubs, groundcover, and lawn. As per PES 2016 application [33], soil conditioner B was made up of 55% organic matter, 10% biodegradable polymer, humid acid, 5% sulfur, and 1% nitrogen (Solution B manufacturer information).

A total of six soil specimens were randomly sampled on site in June 2017 as per PES 2016 soil sampling method (adapted from Britton Harrell [43] in Seguela et al. [33]), before applying Solution B to the remaining 24,402 m^2 of the MFCS landscape to establish soil quality improvement against 2016. The major soil macronutrients and major micronutrients, listed in **Tables 3** and **4**, were tested [23, 44, 45] to compare SEI 2017 Intervention soil quality results against PES March 2016 results [33] as per the method described in Section 2.2. The 2017 soil test results were evaluated against Hornek et al.'s [45], Jensen's [46], and Flynn and Ulery's [47] concentration limits.

For this chapter, the results will firstly be assessed for the 11,000 m^2 of *Pennisetum setaceum* only, which are classified as low-irrigation plants by UPC [29, 30] and require 1.5 kilograms per square meter (kg/m^2) of soil conditioner B. Secondly, the results will provide an account of the remaining 127 outdoor valves water flow audit (135–8 = 127 valves). Thirdly, the results will visually be evidenced.

2.3 Updated pilot calculation one method (PPC1 2016): irrigation rate

2.3.1 Updated literature: UPC (2017) irrigation rate standard

During the construction stage of the MFCS in 2011, the LI demand was estimated by the landscape contractor at 375 m^3/month at peak time (July) [33] based on ADM standard irrigation rate [28]. In 2017, the ADM Standard [28] was announced [36, 48] in Seguela et al. 2017 [33] to be adjusted and aligned to UPC [30] irrigation rate, which was updated and published in August 2017. From the analysis of ADM [28] and UPC [30] irrigation rates, it is observed that UPC [30] revised irrigation rate is 19% lower than the original [29].

The revised UPC manual [30] reflects the findings of Seguela et al. [33], which recommend that when applying both soil conditioner and organic fertilizer the

Soil samples	Year	OM (%)	MC (%)	Ca (mg/kg)	Mg (mg/kg)	K (mg/kg)	N (mg/kg)	Na (mg/kg)
Sample 1	2016	6.16	8.1	40.08	24.31	23.25	50	—
	2017	1.89	2.26	9.62	8.26	15.1	12.3	18.3
Sample 2	2016	1.88	10.7	40.08	29.17	48.7	60	—
	2017	1.77	3.12	7.2	5.3	7.04	2.94	8.98
Sample 3	2016	3.74	5.7	160.32	53.48	34.15	70	—
	2017	2.33	1.34	28	12	8.06	14.35	14.34
Sample 4	2016	2.96	3.5	53.44	32.4	7.35	20	—
	2017	2.17	2.93	44	28	21.16	20.06	38.94
Sample 5	2016	2.06	13	24.04	14.6	4	40	—
	2017	1.21	1.71	29	20	16.34	13.89	18.55
Sample 6	2016	—	—	—	—	—	—	—
	2017	1.89	2.15	26	12	7.07	15.06	12.44

Notes: Organic Matter (OM), Moisture Content (MC), Calcium (Ca), Magnesium (Mg), Potassium (K), Nitrogen (N), Sodium (Na).

Table 3.
SEI 2017 against PES 2016 soil laboratory test results.

Soil samples	Year	pH	EC (ds/m)	SAR (meq/l)	ESP (%)
Sample 1	2016	8.27	1.14	4.02	59
	2017	7.08	0.25	0.89	35.39
Sample 2	2016	8.72	1.00	5.96	63
	2017	7.04	0.18	0.62	31.56
Sample 3	2016	7.93	1.23	0.35	7.5
	2017	7.27	0.31	0.57	22
Sample 4	2016	8.05	0.33	0.66	21
	2017	7.34	0.74	1.13	29.12
Sample 5	2016	8.17	0.17	21.4	93
	2017	7.42	0.50	0.65	21.69
Sample 6	2016	—	—	—	—
	2017	7.46	0.31	0.51	21.06

Notes: Electrical conductivity (EC), sodium absorption ratio (SAR), exchangeable sodium percentage (ESP).

Table 4.
SEI 2017 against PES 2016 soil salinity laboratory test results.

water- and nutrient-holding capacity of the soil increases and water needs decrease while sustaining plant growth. Yet, UPC [30] advocates irrigation application every 3 days during the summer and every 7 to 10 days during winter, contrary to the results of Seguela et al. [33]. See results in Section 3.1 below. It is interesting to note that the UPC revised manual [30] removed the interval days (ID) recommendations within the irrigation rate schedules at pages 162 and 163 but has kept the ID within the text of the manual.

2.3.2 PPC1 2016 against Calc1 2017: Irrigation rates comparison

Pilot irrigation rate calculation one (PPC1 2016), calculated by the author [33] and adapted from U.S. EPA [31, 32], is based on decisive parameters affecting the irrigation requirements [33].

The irrigation budget method [31, 32] is based on the peak irrigation month (Landscape Water Requirement for July) and has been compared with the local irrigation rate from the ADM [28] and UPC [29, 30]. The UPC [29] and ADM [28] standards did not have the same seasonal patterns. For instance, the UPC defined winter as the period from January to March (3 months), whereas the ADM considered it to extend from December to March (4 months). The Pilot Calculation One (PPC1 2016) method follows ADM [28] seasonal patterns because the UPC's new manual [29] no longer includes seasons. The UPC [29] irrigation rate was based on seasonal water reduction by interval day's irrigation patterns according to season, plant maturity, and type of plants. For instance, in July (peak month) the UPC [29] recommended *P. setaceum* be irrigated at a rate of 10 liters per m^2 applied every 2.5 days. The updated UPC irrigation rate [30] recommends 10.2 liters per m^2 every 3 days.

The ADM [28] irrigation rate was based on seasonal water reduction according to seasons and type of plants, which, according to the landscape contractor, was 20 liters per m^2 per day for *P. setaceum* in summer. In comparison, Lee [36] recommends 12 liters per m^2 per day.

In 2018, the UPC [30] irrigation rate was still not mandatory for Operations and Maintenance (O&M) projects not having been rated with the Estidama [48] Pearl Building Rating System [33]. Since ADM is the primary authority for approving construction building permits, the MFCS landscape contractor is following the ADM [28] standard for maintenance projects [49] even though irrigation rate application at operations is not a mandate [28–30, 48, 50].

3. Results

3.1 Reflection on PES 2016 soil enhancement results

In 2016, it was observed the landscape irrigation controller installed at the MFCS was not compatible with the Energy and Management Control System (EMCS) and the two were disconnected systems. The irrigation controller's only function is to provide adequate water quantity to the plant at a defined time. The flow meters monitoring overall LI consumption are connected to the EMCS. It would have been preferable to install flow sensors in addition to the flow meters connected to the EMCS for each valve connected to the irrigation controller to monitor LI consumption. This also may have helped to detect any outdoor water leakage [51, 52], because the landscape contractor would have had direct access to the water reports. For financial reasons, this solution was not pursued by the MFCS. Thus, it was not possible to establish the exact quantity of water saved for the pilot project in relation to the application of solutions A, B, and C.

During the pilot project implementation, solution B water consumption reduction could not be evidenced due to the inaccurate irrigation controller settings (from the valve flow errors) and the inaccurate reading of the uncalibrated flow meters connected to the EMCS. This said, these findings have helped the project team to reevaluate the overall irrigation demand so that the soil enhancement pilot could be truly quantified based on the accurate valve flow and on the EMCS calibrated flow meters [33].

When using ultrapure water, such as air-conditioning condensate water, for landscape irrigation (LI), maintaining optimum soil nutrient levels (primary, secondary, and micronutrients) can be challenging, especially in the first few surface centimeters of the soil [34]. The tendency of the low-salinity water is to strip cations from exchange sites [34, 35, 46, 53]. The stripping process can affect both plant-available nutrients and cations (calcium, magnesium, sodium, potassium, and hydrogen) needed to preserve soil structure. Soil conditioner B increased the Cation Exchange Capacity (CEC) of the soil by sustaining cation (sodium, pH, phosphorous, magnesium, calcium) nutrient-holding capacity. Water-holding capacity dictates the length of time between irrigation events, which are 6 hours for the MFCS as per the landscape contractor irrigation schedule. Additionally, precipitation (including sprinklers and drip irrigation) and soil infiltration rates jointly determine the maximum duration of individual irrigation cycles [34]. The duration was established at 18 minutes by the landscape contractor based on the plants and trees' watering need. This finding will help confirm if soil infiltration is affected by the water quality or other factors such as soil structure, degree of compaction, organic matter content, or chemical make-up [34, 53].

3.2 PES 2016 pilot empirical study versus SEI 2017 intervention results

3.2.1 Soil quality test assessment in 2016 against 2017

As discussed in Section 3.1 above, water quality can influence soil quality and its ability to respond to nutrients. This section provides the soil quality results in 2017 against 2016, after solution B application.

In June 2017, a total of six soil specimens were sampled to establish a soil quality baseline against the 2016 pilot project soil test results (see Section 2.3 above).

The results of the pilot project (PES 2016) have been evaluated according to the recommended soil parameters [45–47] to establish why and how the soil conditioner could help reduce water demand for LI. An independent accredited laboratory was employed by the author to conduct the soil test in March 2016 and June 2017. The main results for 2016 and 2017 sampling tests results are summarized in **Tables 3** and **4**.

Following the soil amendment to the whole site in 2017 with Solution B, the pH results in 2017 for samples one, two, and three provide evidence that the soil is neutral [44]. Most micronutrients tend to be less available when soil pH is above 7.5 [47], which is not the case here. However, sample four, five and six results provide evidence the pH is still slightly alkaline when following Flynn's [44] pH concentration limits, although less so than in 2016.

Table 3 provides evidence that in 2017 nitrogen (N) was low for samples one, three, four, and five and deficient for sample two. The potassium (K) level was at moderate level in samples one, four, and five, and low in samples two, three, and six.

In 2017, the organic matter was moderately high and more uniformly established between all samples than in 2016. The organic matter content can help estimate how much N has been supplied to a plant during the growing season [44]. Each percentage of organic matter credits the plant with N (ibid). This is evidenced in **Table 3**. In 2016, the N level was higher than in 2017 and so was the organic matter. If excessive organic matter is added to the soil, infiltration rates can decline [34]. The 2017 soil test results (**Table 3**) provide evidence that the organic matter in the soil was more linear than in 2016 because the landscape contractor uniformly applied the soil conditioner to the landscape site, which may have balanced N in the soil and therefore strengthened the soil texture. Improving the texture of the soil increases the water-holding capacity. There is generally a strong relationship between soil organic matter, soil texture, and water-holding capacity [34, 35].

An adequate level of soil moisture content helps avoids excessively high soil electrical conductivity (EC) and soil salt concentration [34], as evidenced in **Table 4**; moisture content was more uniformly present in 2017 than in 2016 (**Table 3**). Thus, soil conditioner B improved the soil infiltration rate by balancing the soil salt content with other minerals such as magnesium, calcium, and potassium—which means that in 2016 the soil may have had excessive salt content—decreased the infiltration rate and affected the soil moisture content.

In 2017, the exchangeable sodium percentage (ESP) level in all samples was lower than in 2016, except for samples three and four (see **Table 4**). Yet both soil tests showed a level higher than the recommended limit of 15%, which reveals poor soil infiltration [44, 54]. This may be caused by the quality of irrigation water [35]. However, the ESP limits are not fixed values that are to be rigidly applied to all soils. Sandy soil will tolerate much higher ESP values than clay soil [44, 54] as was the case at the MFCS in 2017.

In 2017, the sodium level is higher than the calcium, magnesium, and potassium levels in samples one and two (see **Table 3**). Samples three, four, and five show more calcium, but sodium exceeds magnesium and potassium in all samples except sample five, which has a slightly higher level of magnesium than sodium and potassium.

In relation to **Table 3**, in 2016 the calcium and magnesium were particularly high in sample three, and potassium was lower than calcium and magnesium in all samples except in sample two. Calcium, magnesium, and sodium concentration limits are different for each plant [23]. The concentration limits for the *Pennisetum setaseum* are not known, but it is common for soil in arid regions to have a high calcium level, as was the case here in 2016 [44]. A soil with too much sodium relative to calcium and magnesium is prone to develop problems with water infiltration (ibid), which was the case in 2017 for samples one and two (**Table 3**). Samples two, three, four, and six (**Table 3**) have a higher level of sodium than magnesium. A low-salinity water, like condensate water, will decrease infiltration [35].

In 2016, sample five provided evidence the soil was sodic, while in 2017 the soil was neither sodic nor saline.

The higher the sodium adsorption ratio (SAR), the more likely water will not infiltrate into the soil. This also depends on the irrigation water salinity [44].

Table 3 results provide evidence that in 2017 the SAR ranges were from 0.57 meq/l (sample three) to 1.13 meq/l (sample four). The EC decreased from 2016 to 2017, ranging from 0.18 meq/l (sample two) to 0.74 meq/l (sample four) in the latter year. According to the results of SAR at the EC observed level [35], the soil shows some infiltration problems.

A soil is classified as sodic when the SAR is above 13, the ESP is above 15%, the EC is less than 2dS/m, and the soil pH is greater than 8.5 [47]. The results show that in 2017, the MFCS soil had a neutral pH, a low SAR, but a high ESP and a low EC. This means that the salinity may be affected by the EC of the irrigation water and so the soil may need to be carefully managed due to its low EC conditions (ibid).

Another factor that might be affecting infiltration is the high evaporation rate of AD, particularly in summer, because soil texture plays an important role in the evaporation process [55]. For instance, fine-textured soils have a stronger capillary action, promoting the evaporation of subsurface soil water and bringing salts to the surface, suppressing the osmotically driven water uptake of plants [55]. Therefore, improving soil texture must be part of the solution, as was observed in July 2017 by visual inspection of the MFCS landscape after the soil was enhanced with Solution B (SEI 2017 Intervention).

The 2017 soil test results demonstrate that balancing pH and salinity levels is important to ensure the implementation of the soil enhancement with soil conditioner B is effective and assessable for water conservation reduction and plant growth optimization. The soil amendment brought the CEC to an acceptable level by sustaining cation (sodium, pH, phosphorous, magnesium, calcium) nutrient-holding capacity. Water-holding capacity dictates the length of time between irrigation events. And precipitation (including rain, sprinkler, drip irrigation) and soil infiltration rates together determine the maximum duration of individual irrigation cycles [34]. This is an important finding, which provides evidence that improving the soil structure also increases the soil's water-holding capacity [34].

3.2.2 SEI 2017 intervention soil conditioner results

One month after the soil B application (June 2017), the irrigation controller was programmed to reduce water by 50%, as per the pilot empirical study two results for the whole landscape. Considering the site of the landscape, it took approximately 2 months (mid-March 2017 to mid-May 2017) to apply solution B to the remaining 24,402 m^2 of the MFCS landscape.

From April 2017 through to September 2017 (6 months), plant (*P. setaceum*) growth was monitored though visual observations and weekly photographic reports for each valve location. The 2017 water consumption was analyzed and reported through the EMCS.

Water-holding capacity and infiltration rates are ultimately linked [34]. Solution B enhanced the water-holding capacity of the soil, resulting in better infiltration of the water into the soil because it improved CEC, as evidenced from the 2017 photographs (**Figure 2**) and the soil test results in 2017 as discussed in Section 3.2.1 above.

Following the 2017 soil test results, it was also found that the addition of gypsum, acting as cation nutrient-holding capacity, was needed to maintain the pH level at neutral (see samples four, five, and six, **Table 3**), and increased calcium in the soil was needed to counteract the higher sodium level (see samples one, two, and four, **Table 3**). Gypsum can help correct soil alkalinity caused by a high ESP [35]. The volume of gypsum to apply is determined by the ESP and base saturation percentage sodium values [34]. Amendments comprising soluble calcium salts or acids, or acid-forming substances will be beneficial [56, 57].

In September 2017, the landscape contractor applied a gypsum solution to balance anions and cations, so that pH and salinity levels are adjusted, and the applied soil conditioner is effective for long-term water conservation and plant growth optimization.

The gypsum solution was applied to the surface of the landscape with the addition of light hand-watering over the surface to settle the gypsum down and avoid the

Figure 2.
SEI 2017 Results—Plant Growth Solution A (left) and B (right).

Total valves	A	B	C	Total Water loss based on 16 hours irrigation time per day (m^3)
	Water loss (liters) every 18mns	Under irrigated plants (liters) every 18mns	Difference in liters (A-B)	
		Controller A		
52	32.46	−5.19	27.27	1.45
		Controller B		
83	60.86	−7.58	53.28	2.84
		Total controller A and B		
135	93.32	−12.77	80.55	4.30
Total water loss per year in m^3				1567.94

Table 5.
SEI 2017 intervention outdoor valve flow audit results (primary data collected by the third-party auditor and analyzed by the main author).

solution B soil conditioner washing away [49]. For this reason, a water amendment, such as chemigation, may be more appropriate for the MFCS to save on manpower cost and time of application [34].

3.2.3 SEI 2017 outdoor valve flow audit results

As discussed in Sections 2.2 and 3.1, the remaining 127 outdoor valve flow was verified (audit initiated by the main author) to minimize further non-potable water loss. Following the application of Solution B for the entire site, the irrigation controller had to be reprogrammed to the new irrigation rate based on ADM standard [28] with 50% water reduction. The reprogramming of the irrigation controller with the revised flow rate in liters per second should help save an additional 1567 m^3 of water per year (see **Table 5**).

Table 5 below shows the results of the 135 valves audited at the site, which provides evidence the MFCS wasted 1567 m^3 of water per year. Most of the valves had a higher flow rate than the As-Built (April 2015 hand-over documents to building operator) documentation records, resulting in the landscape being over-watered by 4 m^3 per day.

4. Discussion

4.1 Revised irrigation rate standards against PPC1 calculation

As discussed in Section 2.3 above, the UPC irrigation rate [30] has been revised since 2010. In 2016, the irrigation rate (UPC) [29] was deemed impossible to apply by the landscape contractor, who feared plants would not survive watering at 2.5-day intervals in the harsh climate, particularly during summer (42.6°C mean maximum temperature during the day). The revised 2017 rate calls for a three-day irrigation interval in summer and 7 to 10 days in winter. Thus, the revised UPC irrigation rate [30] would still be challenging to apply due to high evaporation rate and higher plant water need in summer; the recommended volume of 107 m^3/day is deemed very low (**Figure 3**). This has been evidenced during the pilot conditioner testing (PES 2016). When the LI was reduced to 60% (equivalent to 166 m^3/day) in July 2016, the *Pennisetum setaseum* showed signs of water stress.

It was found that the MFCS irrigation rate after soil improvement was 50% less than the ADM [28] irrigation rate, 35% less than the UPC [30] guidance and 5% above the U.S. EPA LI budget calculation [31]. In summer, that equates to 416 m^3/day [28] against 208 m^3/day (SEI 2017); 321 m^3/day [30] against 208 m^3/day (SEI 2017) and 208 m^3/day (SEI2017) against 198 m^3/day [31], respectively. That means the ADM [28] and the UPC [30] standards in their current state are erroneous, because they encourage landscape professionals to either wastewater by over-irrigating [28] or under-irrigating [30] in the case of the revised irrigation rate (**Figure 3**) based on three-day intervals [30], as discussed with the landscape contractor.

Additionally, it was found that the MOCCAE soil standard [27] does not clearly indicate minimum and maximum soil micro- and macronutrient concentration limits

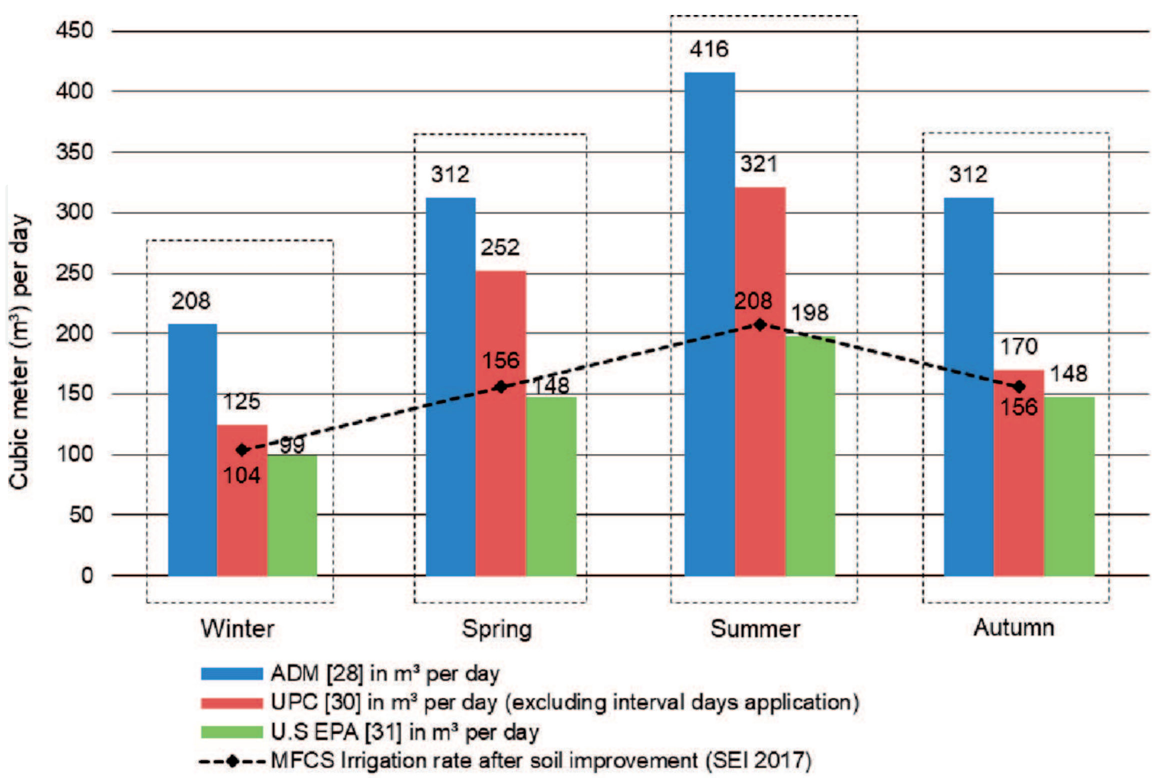

Figure 3.
SEI 2017 Irrigation Rate against ADM [28], UPC [30], and U.S. EPA [31].

for soil maintenance. Moreover, the RSB standard [26] does not include salinity water parameters, which could be beneficial to irrigation water. These two aspects point to the importance of direction from the authority to direct operations and maintenance teams on outdoor water use water and soil quality requirements for UAE climatic conditions, and to promote techniques to increase soil water-holding capacity to prevent soil deficiency and soil infiltration problems.

4.2 Water demand outcome

Calculation one (Calc1 2017) is as per PPC1 2016 calculation one, which aligns with U.S. EPA [31] water budget with 5% adjustment and 50% less than the ADM standard [28] after soil improvement.

In 2016, the LI condensate water deficit was established at 19,235 m^3 against 11,189 m^3 in 2017, predominantly occurring in the winter and spring months, representing a 42% reduction between the 2 years. In 2016, the deficit occurred for 6 months from December to May and in 2017 for 7 months from November to May.

Figure 4 provides a monthly breakdown of the LI consumption for the year 2017 as recorded by the EMCS, against the LI demand based on ADM standard [28].

In addition, and as shown in **Figure 4**, the water consumption does not follow the pattern of the actual water demand of the plants, shrubs, and trees based on the ADM standard irrigation rate [28] before soil amendment. In March, April, and September, more water was consumed than required according to the standard (ibid.). In

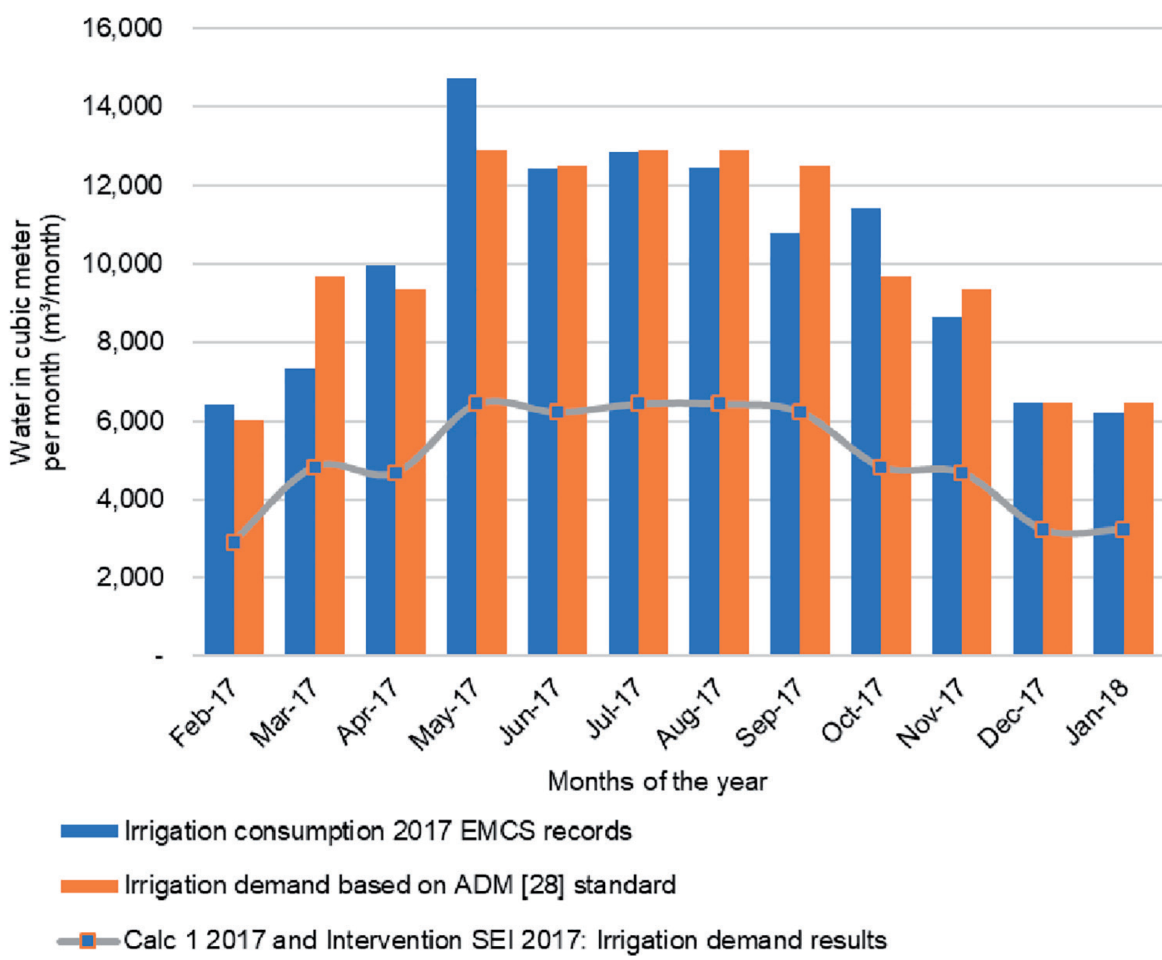

Figure 4.
LI consumption based on 2017 EMCS records against SEI 2017, PPC1 2016, and calculation one (Calc1) results.

addition, from July—the time at which the soil amendment dictated the irrigation rate based on CS1 Calc 1, or 50% less water than the ADM standard [28]—the irrigation was not changed to this new pattern of water demand. Thus, from July through to January 35,100 m^3 of water should have been used for LI, when in fact 65,274 m^3 (an additional 46%) was consumed.

The reason for this excessive water consumption may be either that the landscape contractor did not reprogram the irrigation controller after the 2017 valve flow audit to align with the soil enhancement irrigation rate (SEI 2017 and Calc1 2017), or that there is a leakage outdoors. As of April 2018, the LI and the WFs incurred a condensate water deficit for 7 months of the year. This data analysis provides evidence that the consumption is above the required demand.

The above observations provide evidence of the condensate water deficit for 2017 based on the 2017 EMCS records. From November through to May, there is insufficient condensate water (−11,189 m^3) to feed the 2017 excessive consumption of the LI.

5. Conclusions

The case study presented describes two interventions initiated from April 2016 to September 2017 to increase the water-holding capacity of the soil and thereby save water. Three solutions were tested onsite for 12 months, from March 2016 to March 2017. Soil conditioner B was applied to the remainder of the landscape in April and May 2017, and its impact on water-holding capacity took effect from May to June 2017. A soil test was conducted in June 2017 to evaluate the soil enhancement. The landscape irrigation (LI) valve flow audit was completed in August 2017 for the 127 remaining valves. The reprogramming of the irrigation controller, which aligns with the latter two tasks, was implemented in September 2017. The methodology for soil quality testing, soil conditioner, and valve flow audit application, and irrigation rate calculation have also been discussed.

The findings of the SEI 2017 intervention are threefold. First, the 2017 soil test results provide evidence that the application of gypsum acting as additional cation nutrient-holding capacity was needed in addition to solution B to maintain the pH level at neutral and increase calcium in the soil to counteract the higher sodium level. Second, the MFCS irrigation rate after soil improvement is 50% below the ADM [28] irrigation rate, 35% less than UPC [30] in summer without interval days irrigation, and 5% above the U.S. EPA LI budget calculation [31]. Third, the outdoor valve flow audit helped save 1576 m^3 of water per year during operations and contributing to the reprogramming of the irrigation controller together with an appropriate irrigation rate. The combination of these strategies' implementation helped reduce the A/C condensate water deficit by 42% (−8046 m^3) in 2017 against 2016.

These results provide evidence that, firstly, the ADM [28] standard is applicable only if the soil is amended and the irrigation rate adjusted as per the above method. It was also observed in July 2016 that the UPC standard [29] 2.5-day irrigation interval pattern in summer resulted in plant water stress. Secondly, soils in desert type climates must be amended with both a soil conditioner able to alternate the water-holding capacity of the soil to achieve up to 50% LI reduction and a gypsum solution to balance the pH and anions, to avoid infiltration problems. Thirdly, the most stringent irrigation rate can be applied to a sandy soil in the climatic context of the MFCS only if soil is enhanced to sustain cation nutrient-holding capacity and thereby increase water-holding capacity. This was observed visually in 2016 when solution B was compared with solutions A and C and confirmed in 2017.

These elements point to the importance of direction from the relevant authority to direct operations and maintenance teams on outdoor water use and soil quality requirements for UAE climatic conditions, and to promote techniques to increase soil water-holding capacity to prevent soil deficiency and soil infiltration problems.

This research contributes to the existing body of knowledge in practice by demonstrating that outdoor water demand management has a large role to play in helping minimize water wastage, and thereby decrease GHG emissions, for a medical facility in AD. In addition to this, the authors have demonstrated that a water demand strategy can be used as a decarbonization strategy in AD and may also be transferred to other countries located in arid climates that have limited access to natural resources and depend on desalinated water. The authors, therefore, encourage the UPC [30], ADM [28], and RSB [26] to amend their guidelines and standards by adopting the following recommendations:

- A soil standard should be made available to the public to reflect AD soil and climate conditions.

- The use of soil enhancement techniques for large landscape sites at the design, construction, and operation stage should be mandated to save on water consumption for LI.

- The UPC [30] and ADM [28] irrigation rate should align to the U.S. EPA [31, 32] standard and include the application of soil enhancement as a requirement.

- The commissioning and ongoing commissioning of new buildings' water systems should be mandated to avoid faulty watering rates.

- The RSB [26] recycled water regulations should include salinity parameters for non-potable water to avoid soil infiltration problems.

Other recommendations from this chapter are to:

- Confirm if soil infiltration is affected by water quality or other factors such as degree of soil compaction, organic matter content, or water chemical makeup.

- Supplement the measurements with soil moisture sensors in the field at least at three depths.

- Statically evaluate each sample taken of different depths.

- Include the data of fresh and dry weights of specified plants.

- Test water-binding products improving soil properties for future studies.

Conflict of interest

The authors declare no conflict of interest.

Author details

Geraldine Seguela*, John Richard Littlewood and George Karani
Cardiff Metropolitan University, Cardiff, United Kingdom

*Address all correspondence to: seguelag@gmail.com

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